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This simple method of classification may be recommended as being rapid of operation, and free from the difficulties connected with the comparison of separate photographs with one another. It requires the establishment of a scale of relative-intensity-estimates by the observer, but this is a very simple matter when the range employed is small. To some extent the scale will be dependent upon the dispersion of the spectrograph employed since several of the lines used are compound in character. With the single prism spectrograph at Mount Wilson the same reduction curves have been used successfully for photographs on which the linear dispersion varies from 16 to 90 angstrom units to the millimeter at the center of the spectrum.

In connection with the classification of stellar spectra a number of photographs have been made with a Koch microphotometer of the intensity curves of some of the pairs of lines employed in the comparison. There are numerous practical difficulties connected with the use of this instrument for lines as narrow and as short as those in stellar spectra, and it is doubtful whether the accuracy obtained is of so high an order as to justify the use of so laborious a method for stellar classification. It is probable, however, that it might be used to advantage in the selection of standard stars of reference in which a knowledge of the absolute intensities of certain spectrum lines would be of great value.

INVESTIGATIONS IN STELLAR SPECTROSCOPY. II. A SPECTROSCOPIC METHOD OF DETERMINING STELLAR PARALLAXES

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The question whether the intrinsic brightness of a star may not have an appreciable effect upon its spectrum is one with important applications in astronomy. If two stars which have closely the same type of spectrum differ very greatly in luminosity it is probable that they also differ greatly in size, mass, and in the depth of the atmospheres surrounding them Accordingly we might hope to find in these stars certain variations in the intensity and character of such spectrum lines as are peculiarly sensitive to the physical conditions of the gases in which they find their origin, in spite of the close correspondence of the two spectra in general. If such variations exist and a relationship may be derived between the intensities of these lines and the intrinsic brightness of the stars in which they occur, we have available a means of determining the absolute magnitudes* of stars, and hence their distances.

The first attempt to detect such lines was made by Hertzsprung, who concluded that the strontium line at λ 4077 gave some indication of varying with the absolute magnitudes of the stars in whose spectra it appeared. Quite independently Dr. Kohlschütter in the course of his studies of the classification of the Mount Wilson stellar spectra found two or three lines which appeared to vary in this way, and some results of an application of these lines to the determination of absolute manitudes were published in 1914. Since that time the work has been extended greatly with the aid of the additional material available. The results of the investigation and of an attempt to utilize these criteria for the derivation of stellar distances are contained in this communication.

The first essential in beginning this research was an accurate classification of the stellar spectra into the several types. This was carried out by the method already described (These PROCEEDINGS, **1**, 481). Stars of the same type of spectrum but of very different absolute brightness were then compared with one another, and the relative intensities of the different spectral lines were examined carefully.

To illustrate the procedure we may take as an example the two stars 61^1 Cygni and α Tauri. The parallaxes of these stars are 0.″31 and 0.″07, respectively, and their apparent magnitudes are 5.6 and 1.1. Their absolute magnitudes may be computed from the equation

$$M = m + 5 + 5 \log \pi$$

in which M is the absolute magnitude, m the apparent magnitude, and π the parallax. The absolute magnitudes, accordingly, are 8.0 and 0.4; that is, the luminosity of α Tauri is over 1100 times as great as that of 61^1 Cygni. A comparison of the spectra of the two stars side by side on a Hartmann spectrocomparator shows several points of difference. Of these, two are most important. The calcium line at λ 4455 is very strong in 61^1 Cygni and relatively weak in α Tauri; and the strontium line at λ 4216 is weak in 61^1 Cygni and strong in α Tauri. That this difference in behavior depends upon physical conditions in the stars and is not merely accidental is made almost certain by solar investigations. The line λ 4455 of calcium is greatly strengthened in the spectrum of

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* The absolute magnitude of a star is its apparent magnitude when reduced to unit distance. The unit commonly employed is the distance corresponding to a parallax of 0.″1. On this scale the absolute magnitude of the sun would be 5.5, or 4.8, if more recent, and probably better, values of the sun's photometric brightness are employed.

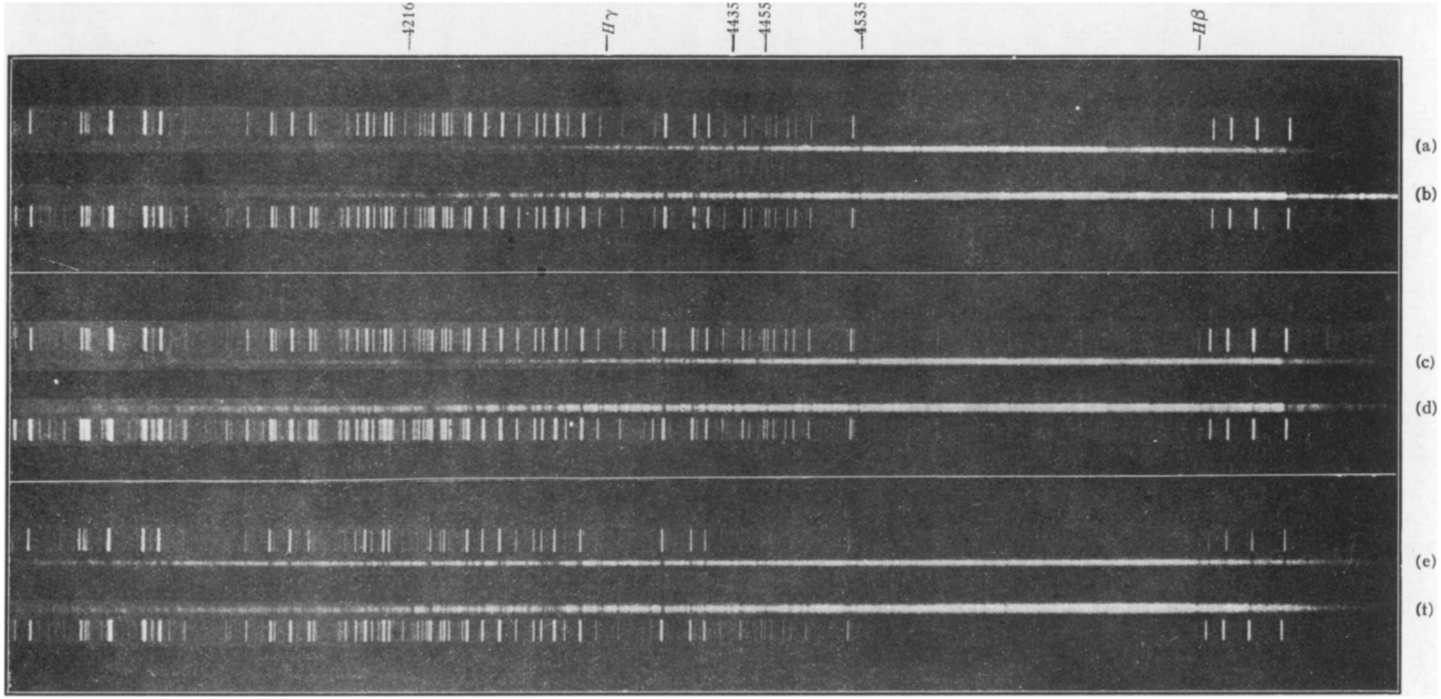

FIG. 1. SPECTRA OF PAIRS OF STARS OF DIFFERENT ABSOLUTE MAGNITUDE SHOWING VARIATION OF THE INTENSITY OF CERTAIN LINES WITH MAGNITUDE.

(a) Groombridge 34; (b) Boss 1560. (c) Lalande 21185; (d) Boss 2921. (e) Piazzi 5^h 146; (f) Boss 1513.

sun-spots, and increases in intensity with reduction in temperature. The line λ 4216 of strontium, on the other hand, is an enhanced line, that is stronger in the spectrum of the spark than of the arc, and is probably a high temperature line. It is very prominent in the spectrum of the sun's limb when photographed at eclipses, and also in the upper chromosphere. Numerous other smaller differences between the spectra of α Tauri and 61^1 Cygni all point in the same direction; the low temperature lines strengthened in sun-spots are stronger in 61^1 Cygni; the enhanced lines are stronger in α Tauri.

It has seemed preferable, however, for two reasons to use only these two lines in the absolute magnitude investigation. First, because they show the effect most markedly; and second, because they appear to be influenced but slightly by closely adjoining lines which blend with them. Among other lines which show the effect plainly, reference should be made to λ 4435 of calcium and λ 4535 of titanium, which are strong in intrinsically faint stars, and to two lines at λ 4395 and λ 4408 which are strong in the brighter stars. The line at λ 4395 is probably due to enhanced titanium. As will appear later, in the course of a discussion of M type stars, the hydrogen lines themselves seem to vary with absolute magnitude, at least in certain types of spectra. This should prove of fundamental importance in further investigations of stellar luminosity.

After the behavior of the two lines λ 4216 and λ 4455 had been examined in a large number of stars, and the systematic differences had been found to persist through a wide range of spectral type, the attempt was made to establish a numerical relationship between the intensities of these lines and the absolute magnitudes of the stars in which they occur. As in the case of the hydrogen lines used for classification purposes, lines were selected near λ 4216 and λ 4455, with which the intensities of these lines were compared, the differences of intensity being estimated on a scale extending from zero to ten. The pairs of lines finally adopted for all of this work are as follows:

(a)	λ 4216, *Sr* and	λ 4250, *Fe*
(b)	λ 4455, *Ca*	λ 4462, *Fe, Mn*
(c)	λ 4455, *Ca*	λ 4495, *Fe*

For convenience of reference these pairs of lines will be designated in the future as (a), (b) and (c). The value (a) = −2, for example, denotes that λ 4216 is estimated to be two units fainter than λ 4250.

As soon as the estimates had been completed a number of the stars with well-determined parallaxes were selected, their absolute magnitudes were computed, and curves were constructed in which the observed differences of intensity for each pair of lines formed the abscissae, and the absolute magnitudes the ordinates. The stars were divided into five groups according to spectral type and curves were drawn for each group. The groups are as follows:

F0–F6; F7–G7; G8–K4; K5–K9; M

The curves are so nearly straight lines in the case of the first three of these groups that straight lines have been adopted, the constants being derived by least square solutions. In the K5–K9 group the curve for (a) is a straight line but not for (b) or (c). It is probable that there are no straight lines in the M group, but this is very uncertain. The significance of a straight line is, of course, that the intensity of the spectrum line varies uniformly with the absolute magnitude.

The most serious difficulty in the construction of these curves is the scarcity of parallax determinations on stars of high luminosity. Parallax observers have confined their attention almost wholly to stars of large proper motion which promise to yield large parallaxes. With the aid, however, of the Yale observations on the very bright stars, and some most valuable determinations by Mr. van Maanen of the parallaxes of certain stars of small proper motion, a number of stars of very high luminosity were selected upon which the lower portions of the curves could be based. Particularly in the cases of the K5–K9 and the M groups these portions of the curves are still most uncertain, and must be adjusted with the aid of additional parallax observations when they become available.

The list of formulae derived for the several groups is given in Table I. The equations are from my own observations. A similar list, in which the constants differ slightly, has been obtained from the determinations of Miss Burwell, who has carried out a complete series of estimations of the line intensities in these stars. In the formulae, M is the absolute magnitude, and Δ the estimated difference of intensity for each of the pairs of lines.

TABLE I

	(a)	(b)	(c)
F0–F6..............	$M = -1.9\Delta + 5.2$	$M = +2.0\Delta + 3.3$	$M = +2.8\Delta - 2.6$
F7–G7..............	$M = -1.4\Delta + 4.9$	$M = +2.0\Delta + 3.3$	$M = +2.8\Delta - 2.6$
G8–K4..............	$M = -1.6\Delta + 4.7$	$M = +1.6\Delta + 5.1$	$M = +2.3\Delta - 0.3$
K5–K9..............	$M = -1.8\Delta + 5.0$	Curve	Curve
M (low luminosity)..	$M = -1.5\Delta + 6.9$	Curve	Curve

The equation and curves in the case of the M stars are applicable only to the stars of low luminosity. In the case of the F0–F6 stars it is doubtful whether the equations given, which for (b) and (c) are the same as in the G group, are other than rough approximations. The enhanced lines in the early F stars are normally so prominent that it is not surprising that the method begins to break down at this point.

To illustrate the use of the formulae and curves we may select as illustrations a few stars of different spectral types and magnitudes. These are collected in Table II. The classification is from Mount Wilson determinations.

TABLE II

STAR	MAG.	TYPE	Δ			M			PARALLAX		
			(a)	(b)	(c)	(a)	(b)	(c)	Mean	Comp.	Obs.
Pi 10^h96....	7.6	F5	−0.7	+0.7	+3.0	+6.5	4.7	5.8	5.7	+0″.04	+0″.04
Sun........		G0	−0.5	+0.5	+3.0	+5.6	4.3	5.8	5.2		
Lal. 38287..	7.2	G5	−1.8	+1.5	+3.5	+7.4	+6.3	+6.2	7.3	+0.10	+0.09
α Arietis...	2.2	K0	+2.5	−2.4	+0.2	+1.0	1.3	+0.2	0.8	+0.05	+0.09
α Tauri....	1.1	K5	+3.0	−2.0	+0.5	−0.4	+1.9	+0.5	0.7	+0.08	+0.07
61^2 Cygni..	6.3	K8	−1.8	+5.8	+7.7	+8.2	9.3	8.9	8.8	+0.32	+0.31
Groom. 34..	8.2	Ma	−2.2	+6.8	+9.2	+10.2	10.5	10.4	10.4	+0.28	+0.28

The parallaxes are computed from the absolute magnitudes by the formula, to which reference has already been made,

$$5 \log \pi = M - m - 5.$$

The results are given in the next to the last column of the table, and the measured parallaxes in the final column.

INVESTIGATIONS IN STELLAR SPECTROSCOPY. III. APPLICATION OF A SPECTROSCOPIC METHOD OF DETERMINING STELLAR DISTANCES TO STARS OF MEASURED PARALLAX

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A definite test of the value of this method of deriving stellar parallaxes can be made only through a comparison with all available data on measured parallaxes. Since the evidence depends directly on individual values it is necessary for this purpose to present tables of a somewhat extended character.

It is evident that in the case of the stars whose absolute magnitudes, as computed from the measured parallaxes have been used in the derivation of the relationship between line intensity and absolute magnitude, the mean values of the magnitude will necessarily be identical with those derived from the formulae. The agreement of the measured and the